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THE RELIABILITY OF [C II] AS A STAR FORMATION RATE INDICATOR

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Abstract. We present a calibration of the star formation rate (SFR) as a function of the [C II] 157.74 μm luminosity for a sample of 24 star-forming galaxies in the nearby universe. In order to calibrate the SFR against the line luminosity, we rely on both GALEX FUV data, which is an ideal tracer of the unobscured star formation, and Spitzer MIPS 24 μm, to probe the dust-enshrouded fraction of star formation. For this sample of normal star-forming galaxies, the [C II] luminosity correlates well with the star formation rate. However, the extension of this relation to more quiescent (Hα EW $\leq$ 10 Å) or ultra luminous galaxies ($L_{\rm TIR} \geq 10^{12}$ $L_{\odot}$) should be handled with caution, since these objects show a non-linearity in the $L_{\rm [C\,II]}$-to-$L_{\rm FIR}$ ratio as a function of $L_{\rm FIR}$ (and thus, their star formation activity). Two possible scenarios can be invoked to explain the tight correlation between the [C II] emission and the star formation activity on a global galaxy-scale. The first interpretation could be that the [C II] emission from photo dissociation regions arises from the immediate surroundings of actively star-forming regions and contributes a more or less constant fraction on a global galaxy-scale. Alternatively, we consider the possibility that the [C II] emission is associated to the cold interstellar medium, which advocates an indirect link with the star formation activity in a galaxy through the Schmidt law.

Key words: galaxies: star formation – ISM: lines and bands – infrared: galaxies – ultraviolet: galaxies

1. INTRODUCTION

The [C II] 157.74 μm line is an important coolant for the neutral and ionized interstellar gas. Since [C II] is the brightest spectral line in most star-forming galaxies (owing for 0.1 to 1% of the FIR emission), it is a potentially powerful tracer of star formation activity. Although [C II] predominantly cools the neutral gas in Photo Dissociation Regions (PDRs), a significant fraction of the [C II] emission can arise from the diffuse ISM (cold neutral + warm ionized), H II regions and quiescent molecular clouds. This ambiguity concerning the origin of the [C II] emission might obstruct a direct link between $L_{\rm [C\,II]}$ and the star formation activity in a galaxy.

Boselli et al. (2002) calibrated the SFR against the [C II] luminosity based on Hα data for 22 normal, late-type galaxies ($10^8 \leq L_{\rm TIR} \leq 10^{10.5}\,L_\odot$), but found a large scatter (factor ~ 10) around the mean trend. In our analysis (De Looze et al. 2011), we benefit from other reliable SFR indicators (FUV and 24 μm) to deduce an improved calibration of the SFR versus $L_{\rm [C\,II]}$ and extend the relation to more IR-luminous objects (up to $L_{\rm TIR} \sim 10^{11.8}\,L_\odot$).

2. SAMPLE AND DATA ACQUISITION

Our sample selection is based on the galaxy sample in Brauher et al. (2008), who assembled all galaxies with available [C II] data from the ISO archive. We restrict our sample to the 38 galaxies which are unresolved in the far-IR with respect to the $\sim 75''$ ISO LWS beam and have been observed in both GALEX FUV and Spitzer MIPS 24 μm bands.

FUV observations have been obtained from the GALEX GR4/5 public release and reduced according to the standard pipeline (Morrissey et al. 2007). The 24 μm images were created from raw data produced by the Multiband Imaging Photometer for Spitzer (MIPS) on the Spitzer Space Telescope. The MIPS Data Analysis Tools (Gordon et al. 2005) were used along with additional processing steps to produce the final images.

Fluxes in the GALEX FUV and MIPS 24 μm bands were obtained within the same aperture as the $\sim 75''$ ISO LWS beam using the source-extracting code SExtractor (Bertin & Arnouts 1996).

3. ANALYSIS AND RESULTS

Considering our aim to calibrate $L_{\rm [C\,II]}$ against the SFR, derived from GALEX FUV and/or MIPS 24 μm data, we have to make sure that the star-forming regions are the dominant contributor to the MIR emission. Therefore, we classified our sample according to their nuclear spectral classification: H II regions/starbursts (16), LINER (8) and Seyfert (14) galaxies. For these different nuclear regimes, we examine the power sources that mainly contribute to the 24 μm emission. Since the Active Galactic Nuclei (AGN) in Seyfert galaxies contribute significantly to the 24 μm emission, while LINERS seem to be more SF dominated (see Figure 1), we calibrate the SFR relation on the combined sample of H II regions/starbursts and LINER galaxies.

In order to calibrate the SFR vs. $L_{\rm [C\,II]}$ relation, we need to select a reference SFR tracer. Considering that a combination of FUV and 24 μm traces the complete star formation activity, we use a combination of FUV with 24 μm data, in which case the latter is applied to corrected the FUV fluxes for internal dust extinction.

We obtain the SFR from the GALEX FUV and 24 μm fluxes following the

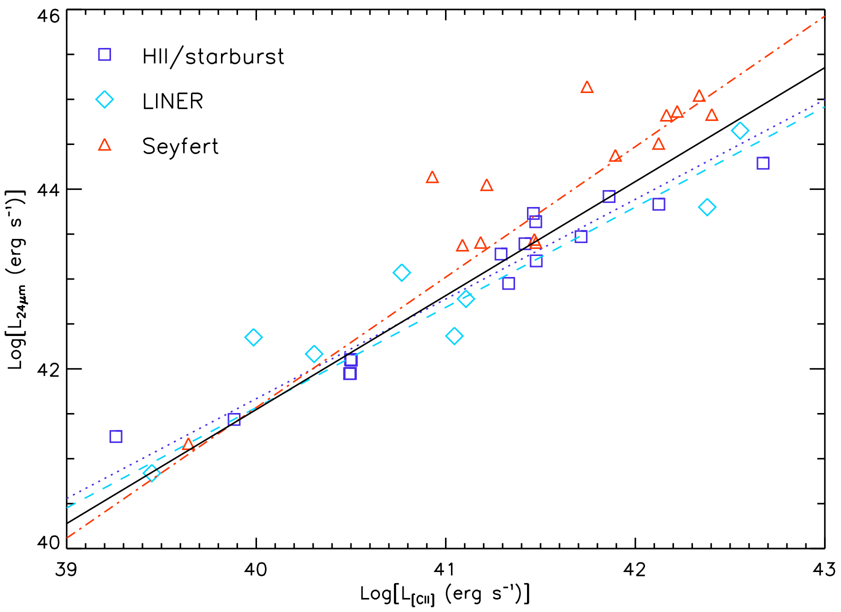

Fig. 1. $L_{[\mathrm{C\,II}]}$ as a function of $L_{24\mu\mathrm{m}}$ for the three subsamples. The best fitting lines through the data points are indicated: the dotted, dashed and dashed-dotted lines are for the H II region/starburst, LINER and Seyfert subsamples, respectively. The mean trend for the complete sample is represented by a solid line.

relation in Zhu et al. (2008) to correct the FUV data for attenuation

$$L_{\mathrm{FUV,corr}}[L_\odot] = L_{\mathrm{FUV,obs}}[L_\odot] + 6.31\, L_{24\mu\mathrm{m}}[L_\odot] \tag{1}$$

and rely on the SFR relation in Kennicutt et al. (2009) to derive a star formation rate from the extinction-corrected FUV data:

$$\mathrm{SFR} = 0.88 \times 10^{-28} L_{\mathrm{FUV,corr}} \tag{2}$$

where the units of $L_{\mathrm{FUV,corr}}$ are in erg s^{-1} Hz^{-1}.

Figure 2 shows that the SFR derived in this manner correlates well with $L_{[\mathrm{C\,II}]}$, with a 1σ dispersion of 0.27 dex around the mean trend. The similar spread around the mean trend in the distance independent plot in Figure 3 confirms this tight correlation (0.26 dex) and, thus, rejects a distance bias influencing the observed trend. From the best fitting line through the data points in Figure 2 we derive this SFR calibration as a function of $L_{[\mathrm{C\,II}]}$:

$$\mathrm{SFR} = \frac{(L_{[\mathrm{C\,II}]})^{0.983}}{1.028 \times 10^{40}} \tag{3}$$

where the SFR and $L_{[\mathrm{C\,II}]}$ are in units of $M_\odot$ yr^{-1} and erg s^{-1}, respectively. The SFR calibration factors are derived assuming a Kroupa (2001) IMF. The relation is valid for star-forming, late-type galaxies with a star formation activity in the range 0.03–127 $M_\odot$ yr^{-1} and a TIR luminosity in between $10^{8.5} \leq L_{\mathrm{TIR}} \leq 10^{11.8}\, L_\odot$.

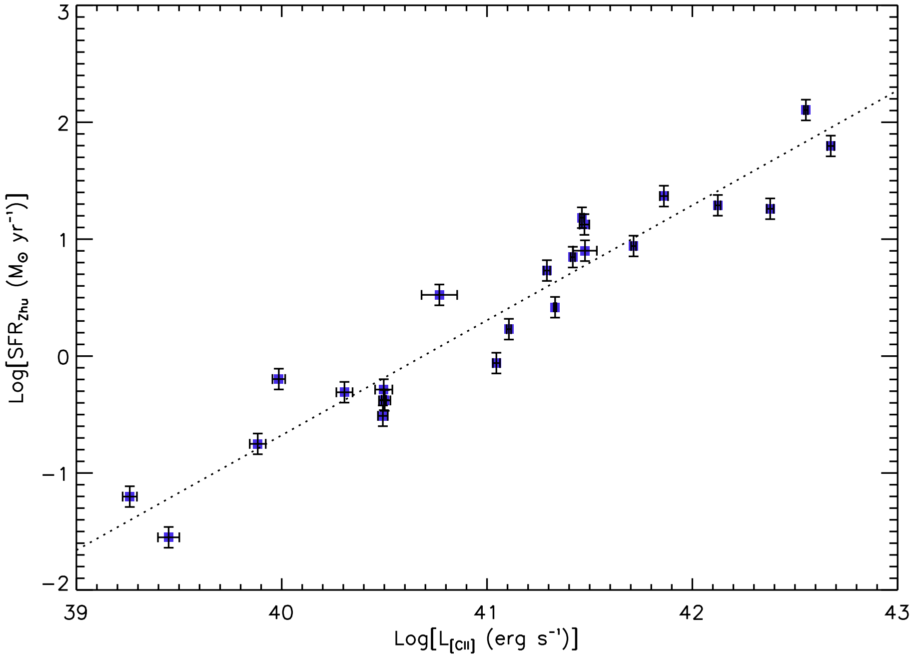

Fig. 2. SFR as a function of $L_{[\mathrm{C\,II}]}$.

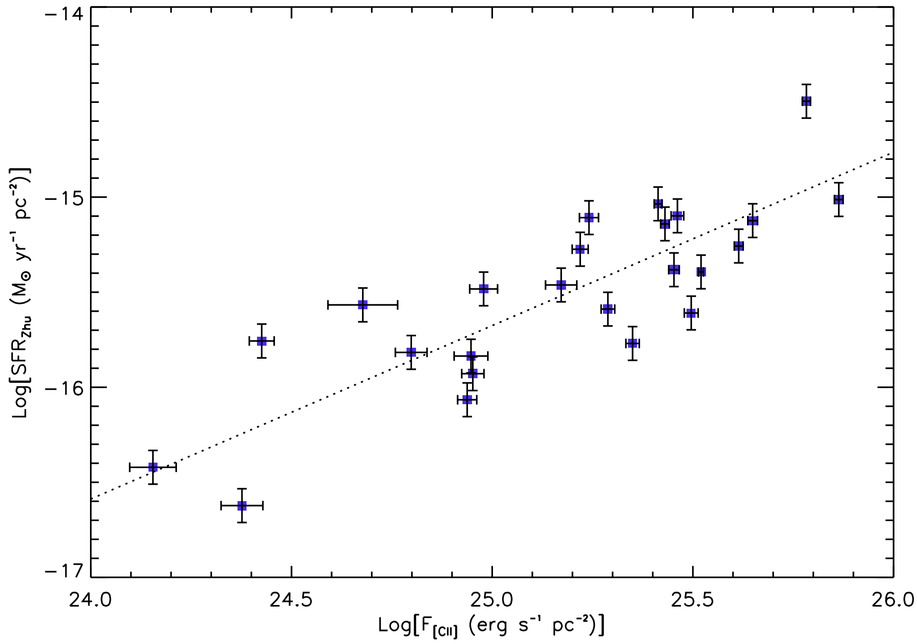

Fig. 3. SFR$/4\pi D^2$ as a function of $F_{[\mathrm{C\,II}]}$.

4. CONCLUSIONS AND PROSPECTS

We have found a tight correlation between the SFR and the [C II] luminosity for a sample of 24 normal star-forming galaxies ($10^{8.5} \leq L_{\rm TIR} \leq 10^{11.8}\, L_{\odot}$) in the nearby universe. Although this relation might not be extendable to more quiescent galaxies (Hα $EW \leq$ 10 Å) an ULIRGs ($L_{\rm TIR} \geq 10^{12}\, L_{\odot}$) due to variations in the gas heating efficiency, it provides a reliable diagnostic for the SFR in normal star-forming galaxies with available [C II] data. Considering that starburst galaxies with $1 \leq z \leq 2$ show a comparable [C II] emission to that found in local star-forming galaxies with similar FIR luminosities ([C II]/FIR $\sim 3 \times 10^{-3}$) (Stacey et al. 2010), our SFR relation might be an important diagnostic for future high redshift surveys (both with Herschel and ALMA).

We provide two possible explanations for the origin of the tight correlation between the [C II] emission and the star formation activity on a global galaxy-scale. A first interpretation could be that the [C II] emission from PDRs arises from the immediate surroundings of star-forming regions. Since PDRs are neutral regions of warm dense gas at the boundaries between H II regions and molecular clouds, and they provide the bulk of [C II] emission in most galaxies, we believe that a more or less constant contribution from these outer layers of photon-dominated molecular clumps to the [C II] emission provides a straightforward explanation for this close link between the [C II] luminosity and SFR. Alternatively, we consider the possibility that the [C II] emission is associated to the cold ISM, which advocates an indirect link with the star formation activity in a galaxy through the Schmidt law. Mapping of [C II] at high resolution is necessary to ascertain the true nature of the tight correlation.

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